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A Method for Assessing Hourly Temperature Probabilities from Limited Weather Records

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ABSTRACT

The frequency distribution of hourly temperature for any month may be assessed with a considerable degree of confidence by use of a nomograph when only the mean monthly temperature and the corresponding monthly extremes are known. Moreover, the method is readily adaptable to computing-machine tabulation and solution.

1. Introduction

This discussion presents a method for assessing hourly-temperature probabilities for any month at a given place when only the *monthly mean* temperature, the *extreme minimum,* and the *extreme maximum* are known.

The method is empirical in the best sense, since it involves predictive generalizations derived from the secular temperature trends shown by actual climatic records for areas between 12 and 70N lat. No mathematical functions are used, since the variables are numerous, complex, and, in many cases, not yet well defined.

The method depends on the statistically demonstrated area-wide similarity of the normalized cumulative frequency curves of observed hourly temperature for given positions of the mean between the absolute extremes. Frequency of any temperature is thus expressed as an empirical and graphical function of that temperature on a normalized 100-scale, the functional parameters being the locations of extremes and the asymmetrical position of the corresponding mean.

The method is simple and direct, and it postulates that probability of future occurrence is dependably related to frequency of past occurrence. Temperatures outside the range of those observed in the past are to be expected, but these will not fall within the range of nomographic prediction.

2. Use of the nomograph

An hourly-temperature nomograph, sections A and B, is shown in fig. 1. The diagram at the upper left deals with July temperatures at Seoul, Korea. The July mean according to thermometer 1 is 77F; the minimum, 57F; and the maximum, 97F. Thermometer 2 is exactly like thermometer 1, except each of the essential temperatures has been reduced by 57F (the minimum). Thus, the reduced minimum becomes 0F; the reduced mean, 20F; and the reduced maximum, 40F. Thermometer 3 is exactly like 1 and 2, except the reduced temperatures of thermometer 2 have been converted (normalized to a 100-scale). Thus, the converted minimum becomes 0; the converted mean, 50; and the converted maximum, 100. The reduced mean, 20 on thermometer 2 was converted by use of the conversion formula at the top of section B:

$$CMn = \frac{100\ (Mn-Mi)}{Mx-Mi} \text{ or } 100\ (Mn-Mi)\ \frac{1}{Mx-Mi}.$$

For example: At Seoul, Korea, the (converted mean)

$$CMn = \frac{100\ (77-57)}{97-57} = 50.$$

Section A of the nomograph *may* be used for the conversion.

(a) Find the reduced mean, 20 (thermometer 2) at the left margin of section A.

(b) Follow the accentuated line to the right to its intersection with the accentuated vertical line, 40—the reduced maximum.

(c) From this intersection, follow the sloping accentuated line up to the right margin. This is the converted mean, 50, and it is also the horizontally accentuated line across the middle of Section B of the nomograph. Where the line of the converted mean intersects the oblique proba-

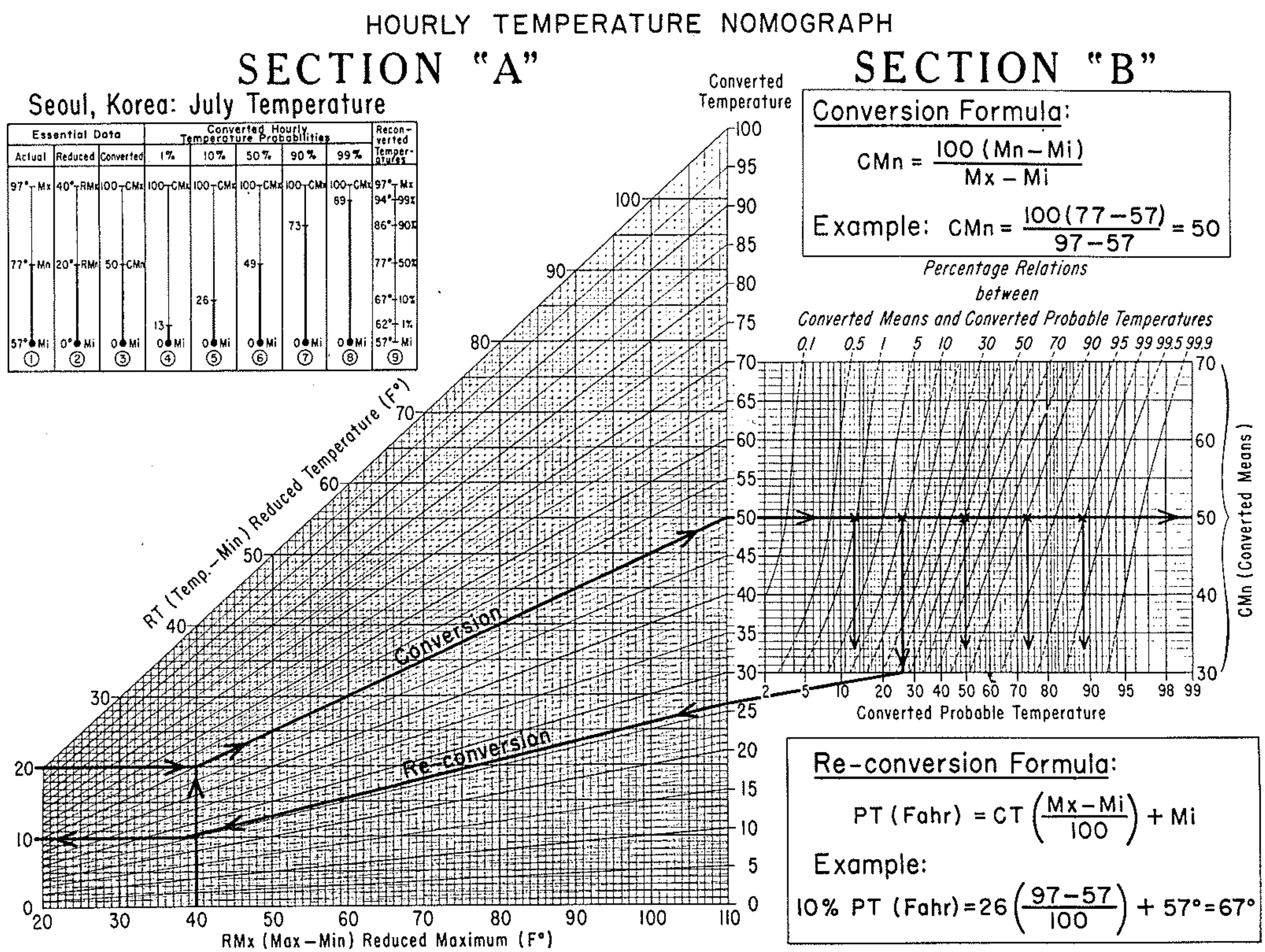

FIG. 1. Nomograph for assessing hourly-temperature probabilities for a given month when only the mean, the extreme minimum, and the extreme maximum are available.

bility percentage lines (1, 10, 50, *etc.*), shown by the X's, the associated converted probable temperatures (CT) are. These temperatures, read at the bottom of section B are: 1 per cent of the time, 13 or lower; 10 per cent, 26 or lower; 50 per cent, 49 or lower; 90 per cent, 73 or lower; and 99 per cent, 89 or lower.

Converted temperatures may be changed to Fahrenheit probable temperatures by use of the reconversion formula at the bottom of section B:

$$PT(\text{Fahr}) = CT\,\frac{Mx-Mi}{100} + Mi.$$

For example, suppose we want to know the hourly temperature to be expected at Seoul 10 per cent of the time; then,

10 per cent PT(Fahr)

$$= 26 \times \frac{97-57}{100} + 57 = 67\text{F}.$$

However, the reconversion may be done by use of section A of the nomograph:

(a) Follow accentuated (CP) sloping line, 26, in section A down to the left to its intersection with vertical line, 40 (reduced maximum).

(b) From this intersection, follow the horizontal accentuated line to 10F on the left margin.

(c) Add the minimum, 57F, and the result is 67F. That is, 10 percent of the July hours at Seoul may be expected to have temperatures of 67F or lower. Conversely, 90 per cent of the time above 67F may be expected.

Five of the converted probable July hourly temperatures for Seoul are shown on thermometers 4 to 8, and, when reconverted to Fahrenheit (thermometer 9), are the hourly temperatures that may be expected the indicated percentage of the time; that is, 1 per cent of the time, 62F or lower; 10 per cent, 67F, or lower; 50 per cent, 77F or lower; 90 per cent, 86F or lower; and 99 per cent, 94F or lower. Conversely, the percentages may be read with reference to the top of the Fahrenheit scale instead of the bottom.

3. Significance of converted means and percentile frequency values

It so happened that the converted mean (CMn) for Seoul in July was 50—a near symmetrical distribution (fig. 2). However, some temperature distributions are skewed so much to the right that the converted mean on the 100-scale may be asymmetrically displaced to as low as 40 (October: Oakland) or even lower, or so much to the left that the converted mean may be as high as 60 (April: Big Delta, Alaska) or even higher. It should be noted here that asymmetry is simply the position of the converted mean between the extreme minimum (0) and extreme maximum (100) on the converted 100-scale, and is not the same as skewness derived by rigid statistical methods. The nomograph provides for all integral converted means from 35 to 65 inclusive and, by interpolation, for five converted means beyond each of these limits. For example, at Oakland, California, the converted mean for October hourly temperature is 40, as shown on this diagram. On the Fahrenheit scale, the maximum is 34 deg above the mean, and the minimum is only 23 deg below. On the other hand, at Big Delta, Alaska, with a converted mean of 60 for April, the Fahrenheit minimum is 59 deg below the mean and the maximum only 34 deg above the mean.

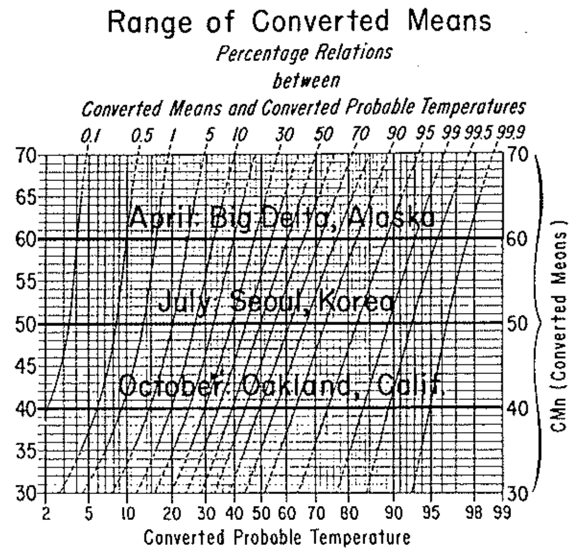

FIG. 2. The asymmetry of converted means when the extremes are converted to 0 and 100, respectively, may range from 30 or lower to 70 or above. Intersections on oblique lines indicate that the hourly-temperature distribution for July at Seoul is near symmetrical, whereas for October at Oakland the converted mean is 40 and for April at Big Delta it is 60.

On the line of each of the converted means (40, 50, and 60), there are 13 fixed values shown by the X's.[1] Each of the 41 horizontal lines of converted means, extending from 30 to 70, inclusive,

[1] Although the nomograph provides converted probable temperatures from 0.1 per cent to 99.9 per cent, the present discussion extends only from 1 per cent to 99 per cent, inclusive.

Table 1. Each of the 31 converted means (first column) is associated with 13 converted probable temperatures (403 in all). The table is a recapitulation in numerical form of fig. 4. For example, the converted temperature values on CM 50 may be read from fig. 4 where the oblique percentage lines cross the 50 CM line. The CT values in this table are vital to machine processing.

PERCENTAGES OF CONVERTED HOURLY TEMPERATURE PROBABILITIES

Means	1%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	99%
35	6	10	15	19	24	28	32	37	43	48	56	69	80
36	6	10	15	19	25	29	33	38	44	50	58	69	81
37	7	12	17	21	26	30	35	39	45	51	59	71	81
38	8	12	18	22	27	31	36	40	47	53	60	72	82
39	8	13	18	23	28	32	37	41	48	53	61	73	82
40	8	14	19	24	29	33	38	43	49	55	62	74	83
41	9	14	20	25	30	34	39	44	50	56	63	75	84
42	9	15	21	25	31	35	40	45	51	57	64	76	84
43	10	16	21	26	32	36	41	46	52	58	65	77	85
44	10	16	22	27	33	37	43	48	54	59	67	77	85
45	11	17	23	28	34	38	44	49	55	60	68	78	86
46	11	17	23	29	35	39	45	50	56	61	69	79	87
47	12	18	24	29	36	40	46	51	57	63	70	80	87
48	12	18	25	30	37	41	47	52	59	64	71	81	88
49	12	19	26	31	38	42	48	53	60	65	72	81	88
50	13	20	26	32	39	43	49	54	61	66	73	82	89
51	13	20	27	33	40	44	50	56	62	67	74	83	89
52	14	21	28	33	40	45	51	57	63	68	75	83	89
53	14	21	28	34	41	46	53	58	64	69	76	84	90
54	14	22	29	35	42	47	54	59	65	70	77	85	90
55	14	22	30	36	43	48	55	60	66	71	78	86	91
56	15	22	30	36	44	50	56	61	67	72	79	86	91
57	15	23	31	37	45	51	57	62	68	73	79	87	92
58	15	24	31	38	46	52	58	64	69	74	80	88	92
59	16	24	32	38	47	53	59	65	70	75	81	88	93
60	16	24	33	39	48	54	60	66	71	76	82	89	93
61	16	25	33	40	49	55	61	67	72	77	82	89	93
62	16	25	34	41	50	56	62	68	73	78	83	90	94
63	16	26	34	42	51	57	63	69	75	79	84	90	94
64	17	26	35	43	52	58	64	70	76	80	85	91	95
65	17	27	36	43	53	59	65	71	77	81	86	91	95

Table 2. Ten stations used in constructing the first draft of hourly-temperature nomograph. In this table, each converted mean (CM) is paired with its associated 10-percentile converted temperature (CT) frequency (see fig. 4).

FORTY CONVERTED MONTHLY MEAN TEMPERATURES PAIRED WITH ASSOCIATED CONVERTED TEN-PERCENTILE TEMPERATURE FREQUENCIES

Station	January		April		July		October	
	C.M.	C. 10%	C.M.	C. 10%	C.M.	C. 10%	C.M.	C. 10%
Berlin, Germ.	59	34	39	19	46	28	45	21
Boston, Mass.	47	27	46	23	42	22	43	23
Dhahran, Arabia	41	22	43	23	46	20	44	23
Glasgow, Mont.	56	32	49	30	50	20	52	28
Kunming, China	58	32	59	37	49	31	55	33
Rome, Italy	46	23	48	23	47	20	47	23
St. Louis, Mo.	48	27	46	21	44	26	50	28
Seoul, Korea	53	28	43	19	49	28	49	24
Warrington, Eng.	62	38	42	23	41	23	47	27
Yuma, Ariz.	43	16	48	25	52	28	52	27

is crossed by 13 oblique percentage lines, making, in all, 533 such intersections. Each of these intersections has a fixed converted temperature value. Thus, any weather station having the essential recorded temperatures has its converted mean and associated converted hourly temperature frequencies on the nomograph.

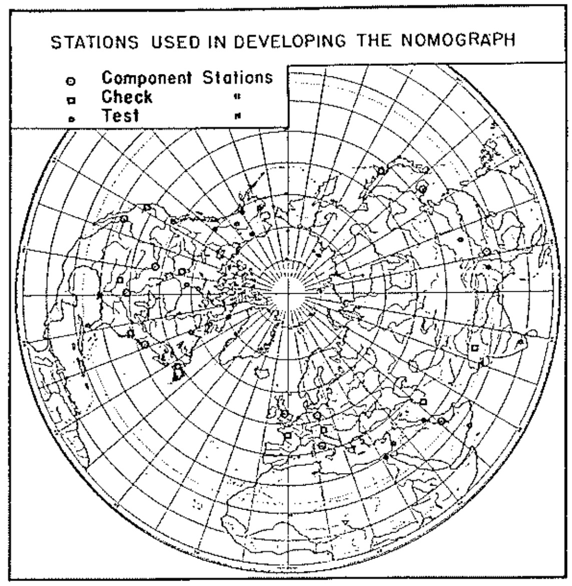

Fig. 3. The map shows the location of the 40 weather stations where hourly temperature records for January, April, July, and October were available.

4. Converted temperature frequency table and machine tabulation

Table 1 lists 31 converted means (column 1) and, for each, 13 associated converted temperatures, or 403 in all. It should be emphasized at this point that the 31 converted means, representing varying degrees of positive or negative asymmetry of the mean, are each associated with 13 fixed converted hourly probable temperatures. In fact, the task of going through the maze of section B of the nomograph may be avoided by substituting the fixed values in the table.

Moreover, these 403 fixed temperature values and the probable hourly temperatures for any month, may be entered on 31 machine punch cards, and they may be found quickly and easily for any or many stations by giving the machine the three items of essential data (mean, maximum, and minimum) and wired instructions for sorting the deck of punched cards. (See formulas on fig. 1, section B).

5. Constructing the nomograph

Of the 10 encircled stations shown on the map (fig. 3), 4 are in the United States, 3 in Europe, and 3 in Asia. The mean, the minimum, the maximum, and the percentage frequencies of hourly temperatures were available for January, April, July, and October for each of the 10 sta-

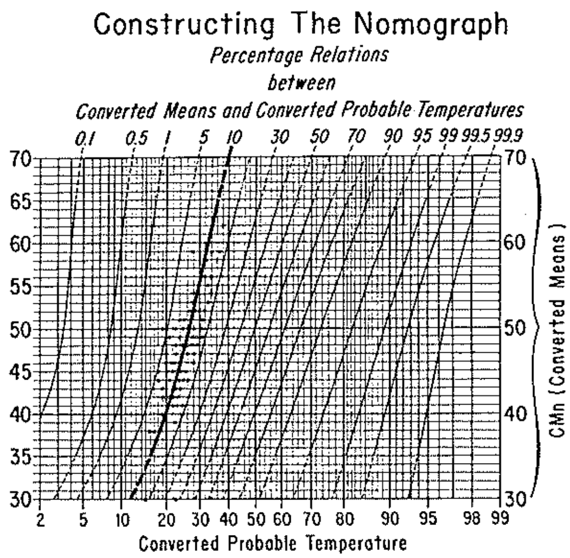

FIG. 4. Each of the sloping percentage lines was drawn through and among 80 pairs of plotted temperature values. The 40 pairs shown by black dots in the vicinity of the 10-percentile frequency line are given in table 2. For example, Berlin in January has a converted mean (CM) of 59, and 10 per cent of the time the hourly converted temperature (CT) was 34 or lower.

tions. By use of the formula previously demonstrated, the recorded temperatures for each of the four months for these 10 stations were converted (normalized) to the 100-scale. This meant, for example, that there was a 10-percentile converted temperature (CT) value paired with each of the forty converted means (table 2). From the plotting of these 40 paired values by black dots on coordinate paper (fig. 4), a 10-percentile curve was drawn.[2] Each of the percentile curves from 0.1 per cent to 99.9 per cent were located in the same manner. Thus, the first draft of the nomograph was constructed.

6. Refining the nomograph

Subsequently, corresponding data from 10 other widely scattered stations, shown by squares on the map (fig. 3), were processed in the same manner and likewise plotted by use of circles on the same coordinate grid (fig. 4) in order to refine and validate the frequency curves. Each percentage frequency line, plotted and thus adjusted, became the visual "best fit" that could be drawn through and among 80 pairs of plotted values. Since the hourly temperature records for the 20 stations varied from 3 to 15 yr (about 2,232 to 11,160 hr), it is presumed that the validity of the curves would be measurably increased if the records were longer and of equal duration.

7. Further validation

The performance of the nomograph was tested on 40 widely scattered stations from Bangalore, India (12N lat), northward to Clyde River, Baffin Land (70N lat), and from Nome, Alaska eastward to Chitose, Japan (fig. 3). For each of these stations, there was available an hourly-temperature frequency record for January, April, July, and October. These actual temperatures were processed by use of the nomograph from the three items of essential data for the 13 percentile levels (1 per cent, 5 per cent, 10 per cent, *etc.*, to 99 per cent). The diagram (fig. 5) summarizes the divergence (+ or −) of the nomographic hourly-temperature frequencies from the actual recorded frequencies for each of the 4 months. Of the divergences, 91 per cent were 3 F-deg or less, and 98 per cent were 5 F-deg or less. The greatest divergences in Fahrenheit degrees were in continental middle and high latitudes where temperature ranges were greatest. About 9 per cent of the probable temperatures according to the nomograph diverged by more than 3 F-deg from the actual temperature frequency.

8. Factors limiting the use of the nomograph

The nomograph herein described was designed for universal use in assessing hourly-temperature frequencies from abbreviated weather records for any month from 12N to 70N lat. It is assumed that the variables inherent in the records used are operative in the performance of the nomograph. Since the hourly-temperature records for the twenty stations used in constructing the nomograph varied from about 2232 hr in January (New Delhi) to 11,160 hr in January (Oakland), it is recognized that the validity of the nomographic curves would be increased measurably if the records covered equal time spans of eight or ten years' duration. It is suggested, therefore, that the nomograph must be considered a tentative instrument, subject to refinements as longer records become available, as broader areal coverage is attained, and as hourly temperature data for the other eight months of the year are recorded and processed.

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[2] Normal probability paper was used because it furnished a wide lateral spread on the nomograph for the tails of the frequency distribution.

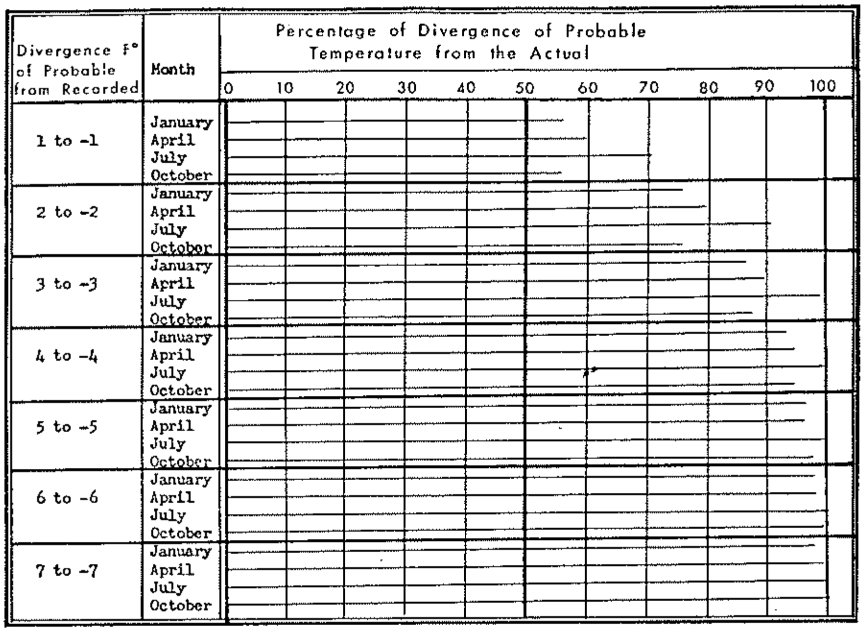

FIG. 5. The 40 stations summarized in this diagram include the 20 used in constructing the nomograph (see fig. 3). Each of the 7 bars for January summarizes the divergence of 520 nomographic temperature predictions from 520 recorded values (13 percentile levels for each of 40 stations). For example, 56 per cent of the January predictions departed from the recorded values by only 1 F-deg or less. (See top bar.) Conversely, 44 per cent of the predictions departed from the recorded values by more than 1 F-deg. The bars for the other departures and other months are to be read in a similar manner.

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